

Neutrino Catalyzed Diphoton Excess

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Abstract

In this paper we explain the 750 GeV diphoton resonance observed at the run-2 LHC as a scalar singlet \mathbb{S} , that plays a key rule in generating tiny but nonzero Majorana neutrino masses. The model contains four electroweak singlets: two leptoquarks, a singly charged scalar and a neutral scalar \mathbb{S} . Majorana neutrino masses might be generated at the two-loop level as \mathbb{S} get nonzero vacuum expectation value. \mathbb{S} can be produced at the LHC through the gluon fusion and decays into diphoton at the one-loop level with charged scalars running in the loop. The model fits perfectly with a wide width of the resonance. Constraints on the model are investigated, which shows a negligible mixing between the resonance and the standard model Higgs boson.

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I. INTRODUCTION

The standard model (SM) of particle physics fits perfectly with almost all the experimental observations in the elementary particle physics. But there are still hints of new physics beyond the SM. The discovery of the neutrino oscillations has confirmed that neutrinos are massive and lepton flavors are mixed [1], which provided the first evidence for physics beyond the SM. An attractive approach towards understanding the origin of small neutrino masses is using the dimension-five Weinberg operator [2]

$$\frac{1}{4}\kappa_{gf}\overline{\ell_{Lc}^C}^g\varepsilon_{cd}H_d\ell_{Lb}^f\varepsilon_{ba}H_a + \text{h.c.} \quad (1)$$

where ℓ_L is the left-handed lepton doublet, H is the SM Higgs. The operator, which might come from integrating out some new superheavy particles, gives Majorana masses to active neutrinos after the spontaneous breaking of the electroweak symmetry. A simple way to realize the Weinberg operator is through the tree-level seesaw mechanisms [3–5]. But the canonical seesaw scales are usually too high to be accessible by colliders. Many TeV-scale seesaw mechanisms were proposed motivated by the testability, some of which give rise to the Weinberg operator at the loop level.

Recently both the ATLAS [6] and CMS [7] collaborations have observed a new resonance at an invariant mass of 750 GeV in the diphoton channel at the run-2 LHC with center-of-mass energy $\sqrt{s} = 13$ TeV. The local significance is 3.6σ and 2.6σ for ATLAS and CMS respectively. The best fit width of the resonance from the ATLAS is about 45 GeV and the corresponding cross section is about $10 \sim 3$ fb, while the CMS result favors the narrow width, which has $\sigma(pp \rightarrow \gamma\gamma) \approx 2.6 \sim 7.7$ fb with $\Gamma \approx 0.1$ GeV. If confirmed, it would be another hint of new physics beyond the SM. According to Landau-Yang theorem [8, 9], this resonance can only be spin-0 or spin-2 bosonic state. The heavy quarks and/or gluon fusion production of the resonance are favored, because the run-1 LHC [10, 11] at $\sqrt{s} = 8$ TeV did not see significant excess at the 750 GeV. It is intriguing to investigate the physics behind this excess as done in a bunch of papers [12–50]. Especially it would be more interesting if a new physics can explain both the diphoton excess and other unsolved problems of the SM, such as neutrino masses and dark matter.

In this paper, we explain both the diphoton excess and the active neutrino masses in a concrete model. The model extends the SM with four scalar singlet: one neutral scalar \mathbb{S} , one singly charged scalar Θ and two leptoquarks Φ and Ω transforming as $(\bar{3}, 1, 4/3)$ and

$(\bar{3}, 1, 1/3)$ under the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$. Θ interacts with the left-handed lepton doublets, Ω interacts with the left-handed lepton- and quark- doublets, Φ interacts with the right-handed leptons and down-type quarks. In addition there is a quartic interaction of the type $\hat{\lambda} \mathbb{S} \Phi^\dagger \Omega \Theta + \text{h.c.}$. In this way Majorana neutrino masses can be generated at the two-loop level as \mathbb{S} gets vacuum expectation value (VEV). Elements of neutrino mass matrix are proportional to the charged lepton and down-type quark masses, and are suppressed by the loop factor. Thus one can naturally derive the electro-volt scale Majorana neutrino masses with new particles at the TeV scale. Furthermore, the observed 750 GeV diphoton excess can be explained as the scalar \mathbb{S} , which is produced through the gluon fusion at the LHC. The ratio of $\Gamma(\mathbb{S} \rightarrow gg)/\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$ is of $\mathcal{O}(25)$, which is the typical character of this model. The wide width of \mathbb{S} can be explained if either charged scalars are slightly lighter than $m_{\mathbb{S}}/2$ or \mathbb{S} is the mediator of the hidden valley. We further point out that \mathbb{S} might play important rule in the spontaneous breaking of a local $U(1)_{B+L}$ gauge symmetry, which was already studied in Ref. [49]. Constraints on the model from the run-1 LHC are studied. Leptoquarks are supposed to mainly couple to the third generation, or couple to the hidden valley, so as to escape the collider search constraints. The mixing angle of the resonance with the SM Higgs is constrained as $\theta < 0.067$, assuming $\Gamma(\mathbb{S} \rightarrow \gamma\gamma) \sim 0.05$ GeV. Furthermore the model may have gauge couplings unification by introducing an extra quadruplet scalar.

The remaining of the paper is organized as follows: In section II we study how to generate Majorana neutrino masses at the two-loop level. In section III, we investigate the possibility of explaining the diphoton excess as the scalar \mathbb{S} in our model. Constraints and further predictions are given in section IV. The last part is concluding remarks.

II. NEUTRINO MASS

In the SM neutrinos are massless, both the lepton number and lepton flavors are conserved. Reactor, solar, atmosphere and accelerator neutrino experiments have discovered neutrino oscillations, which means neutrinos have tiny but nonzero masses. The origin of neutrino masses is still an open question. Seesaw mechanisms are probably the most natural way to understand the smallness of neutrino masses. But elegant traditional seesaw mechanisms are not accessible by colliders, because either the seesaw scales are too high

or the couplings of the seesaw particles with the SM fields are too tiny. Motivated by the testability, many TeV-scale seesaw models [51–53] were proposed. In this section we propose a new TeV-scale seesaw model, which generate neutrino masses at the two-loop level. The new seesaw model extends the SM with four electroweak singlets: two scalar leptoquarks Φ and Ω transforming as $(\bar{3}, 1, 4/3)$ and $(\bar{3}, 1, 1/3)$ respectively under the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$, one singly charged scalar Θ transforming as $(1, 1, 1)$ and a neutral scalar \mathbb{S} transforming as $(1, 1, 0)$. New interactions can be written as

$$\mathcal{L} \supset \hat{Y}_\Theta \ell_L^T i \sigma_2 \ell_L \Theta + \hat{Y}_\Omega q_L^T i \sigma \ell_L \Omega + \hat{Y}_\Phi E_R^T d_R \Phi - V(\mathbb{S}, \Phi, \Omega, \Theta) \quad (2)$$

where ℓ_L is the left-handed lepton doublet, q_L is the left-handed quark doublet, E_R and d_R are right-handed charged leptons and down-type quarks respectively. The new scalar potential takes the form

$$\begin{aligned} V(\mathbb{S}, \Phi, \Omega, \Theta) \supset & -\mu_{\mathbb{S}}^2 \mathbb{S}^\dagger \mathbb{S} + \lambda_{\mathbb{S}} (\mathbb{S}^\dagger \mathbb{S})^2 + \mu_\Theta^2 \Theta^\dagger \Theta + \mu_\Phi^2 \Phi^\dagger \Phi + \mu_\Omega^2 \Omega^\dagger \Omega + g_{\Theta\mathbb{S}} (\Theta^\dagger \Theta) (\mathbb{S}^\dagger \mathbb{S}) \\ & + g_{\Phi\mathbb{S}} (\Phi^\dagger \Phi) (\mathbb{S}^\dagger \mathbb{S}) + g_{\Omega\mathbb{S}} (\Omega^\dagger \Omega) (\mathbb{S}^\dagger \mathbb{S}) + \{\sqrt{2} \hat{\lambda} \mathbb{S} \Theta \Phi^\dagger \Omega + \text{h.c.}\} + \dots \end{aligned} \quad (3)$$

where dots denotes terms that are irrelevant to our study. Notice that interactions in Eqs. (2) and (3) have a global $U(1)$ lepton number (L) symmetry by setting $L_{\mathbb{S}} = -2$. It might be spontaneously broken as \mathbb{S} gets non-zero vacuum expectation value (VEV), $\mathbf{v}_{\mathbb{S}}$, at the TeV scale. For the case \mathbb{S} being a complex scalar, there will be a massless goldstone boson, which is severely constrained by the big bang nucleosynthesis [72] and observations of Bullet Cluster galaxies [73]. To avoid this problem, one might add the soft $U(1)_L$ breaking mass term i.e. $\mu_R^2 (\mathbb{S}^2 + \text{h.c.})$ to the potential without introducing any other trouble. Alternatively, if \mathbb{S} itself is a real scalar singlet, there will be no massless goldstone boson. Actually, this model can be embedded into a theory with local $U(1)_{B+L}$ gauge symmetry¹, where anomalies might be cancelled by introducing colorless vector-like fermions [54]. For the systematic studies of local $U(1)_B \times U(1)_L$ gauge symmetries, we refer the reader to Refs. [55–57] for detail. After \mathbb{S} getting non-zero VEV, the mass eigenvalues of scalars can be written as

$$M_\Theta^2 = \mu_\Theta^2 + \frac{1}{2} g_{\Theta\mathbb{S}} \mathbf{v}_{\mathbb{S}}^2, \quad M_\Omega^2 = \mu_\Omega^2 + \frac{1}{2} g_{\Omega\mathbb{S}} \mathbf{v}_{\mathbb{S}}^2 \quad M_\Phi^2 = \mu_\Phi^2 + \frac{1}{2} g_{\Phi\mathbb{S}} \mathbf{v}_{\mathbb{S}}^2. \quad (4)$$

Given the Yukawa interactions in Eq. (2), neutrino masses can be generated at the two-loop level. The relevant feynman diagram is given in Fig. 1. Neutrino mass elements can

¹ We only point out this possibility, but not focus on this scenario in the rest of the paper.

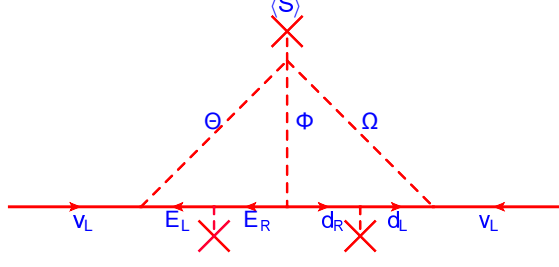


FIG. 1: Feynman diagram that generates neutrino masses at the two-loop level.

be written in terms of loop functions and Yukawa couplings

$$(M_\nu)_{ij} = \frac{1}{1 + \delta_{ij}} \sum_{kl} \left[(\hat{Y}_\Theta)_{ik} (\hat{Y}_\Phi^*)_{kl} (\hat{Y}_\Omega)_{lj} + (\hat{Y}_\Theta)_{jk} (\hat{Y}_\Phi^*)_{kl} (\hat{Y}_\Omega)_{li} \right] \hat{\lambda}_{\mathbf{v}_S} \hat{m}_l^d \hat{m}_k^e I_{kl} \quad (5)$$

where m_k^e and m_l^d are mass eigenvalues of the charged leptons and down-type quarks respectively, I_{kl} is the loop function, which can be written as

$$I_{kl} = \int \frac{d^4 k}{(2\pi)^4} \int \frac{d^4 l}{(2\pi)^4} \frac{1}{P_\Theta^2 - M_\Theta^2} \frac{1}{P_\Omega^2 - M_\Omega^2} \frac{1}{P_\Phi^2 - M_\Phi^2} \frac{1}{P_k^2 - (m_k^e)^2} \frac{1}{P_l^2 - (m_l^d)^2} \quad (6)$$

We refer the reader to Refs. [52, 53] for the calculation of this integral in detail. Apparently neutrino masses, generated through Eq. (5), are suppressed by the charged lepton and down-type quark masses as well as the loop factor. All seesaw particles can be at the electroweak scale and the model is detectable at the LHC. A systematic study the neutrino phenomenology and collider signatures induced by this model, which are interesting but beyond the reach of this paper, will be given in a longer paper. Here we only estimate the size of parameters in Eq. (5) constrained by the active neutrino masses. The integral I_{kl} was calculated analytically in Ref. [74], which has

$$I_{kl} \propto \frac{1}{256\pi^4} \frac{1}{M^2} \frac{\pi^2}{3} \tilde{I}, \quad M \equiv \max(M_\Theta, M_\Omega, M_\Phi) \quad (7)$$

where $\tilde{I} \sim 1$ for a large range of scalar masses. Assuming $M \sim 400$ GeV, $v_S \sim 1$ TeV and $\hat{\lambda} \sim 0.1$, one has $\hat{Y}_X \sim \mathcal{O}(0.1)$ ($X = \Theta, \Omega, \Phi$) to generate active neutrino masses at the sub-eV scale.

III. LHC DIPHOTON EXCESS

Both the CMS and ATLAS experiments have observed the diphoton excess at $m_{\gamma\gamma} = 750$ GeV. The cross section is estimated as $\sigma(pp \rightarrow \gamma\gamma) \approx (6 \pm 3)$ fb for CMS [7] and

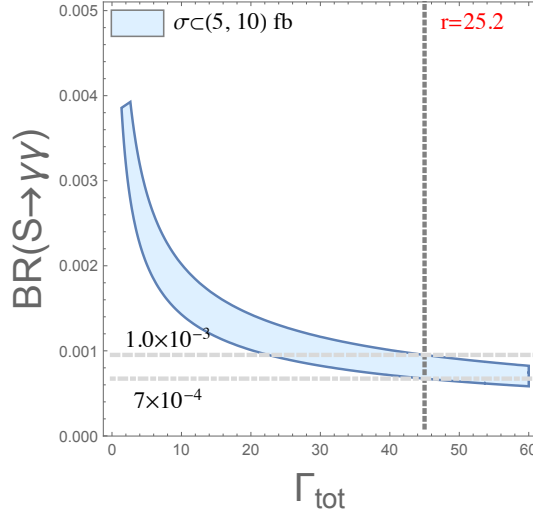


FIG. 2: The region in the $\Gamma_{\text{tot}}^{\mathbb{S}} - \text{BR}(\mathbb{S} \rightarrow \gamma\gamma)$ plane that has $\sigma(gg \rightarrow \mathbb{S} \rightarrow \gamma\gamma) \in (5, 10)$ fb, the vertical line has $\Gamma_{\text{tot}}^{\mathbb{S}} = 45$ GeV; the dot-dashed and dashed horizontal lines correspond to $\text{BR}(\mathbb{S} \rightarrow \gamma\gamma) = 7 \times 10^{-4}$ and 1×10^{-3} respectively.

(10 ± 3) fb for ATLAS [6] at the $\sqrt{s} = 13$ TeV. Besides, the best fit width is about 45 GeV from the ATLAS result, while the CMS result favors the narrow width scenario. If confirmed, the excess would be a solid evidence of new physics beyond the SM. In this section, we explain this resonance as the scalar \mathbb{S} , that plays the key rule in generating active neutrino masses at the two-loop level. Furthermore, \mathbb{S} might also be the particle breaking the local $U(1)_{B+L}$ gauge symmetry spontaneously through the Higgs mechanism [49]. In this way the diphoton resonance might be a hint of new symmetries beyond the SM. The signal of the resonance at the LHC is

$$\sigma(pp \rightarrow \mathbb{S} \rightarrow \gamma\gamma) = \frac{1}{s} \frac{\Gamma_{\text{tot}}^{\mathbb{S}}}{M} C_{gg} \text{BR}(\mathbb{S} \rightarrow gg) \text{BR}(\mathbb{S} \rightarrow \gamma\gamma), \quad (8)$$

where \sqrt{s} is the centre-of-mass energy, M is the mass of \mathbb{S} , C_{gg} and $C_{q\bar{q}}$ are dimensionless partonic integrals, $\text{BR}(\mathbb{S} \rightarrow XX)$ and $\Gamma_{\text{tot}}^{\mathbb{S}}$ are the branching ratio and total decay rate of \mathbb{S} . Considering $C_{gg} \gg C_{q\bar{q}}$ and $\text{BR}(\mathbb{S} \rightarrow q\bar{q})$ is loop suppressed in our model, gluon fusion turns out to be the dominant production channel at the LHC.

The decay rate of \mathbb{S} can be written as

$$\Gamma(\mathbb{S} \rightarrow gg) = \frac{\alpha_s^2 m_{\mathbb{S}}^3}{128\pi^3} \left| \sum_X \frac{1}{2} \frac{g_X \mathbf{v}_{\mathbb{S}}}{M_X^2} A(\tau_S) \right|^2 \quad (9)$$

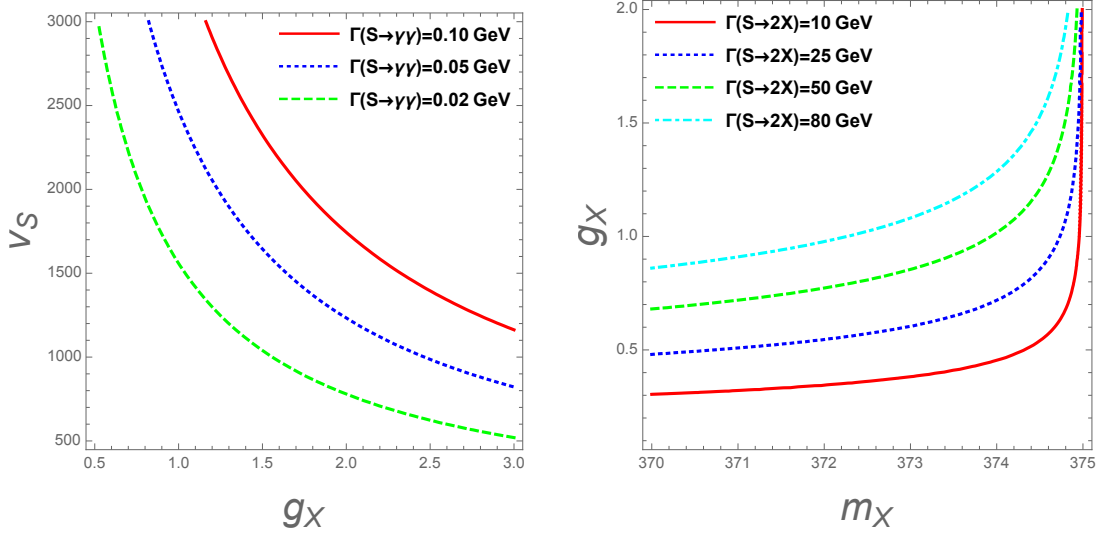


FIG. 3: Left panel: contours of the $\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$ in the g_X - v_S plane, where g_X is the universal coupling between \mathbb{S} and other new scalars; Right panel: contours of $\Gamma(\mathbb{S} \rightarrow 2X)$ in the M_X - g_X plane by setting $v_S = 2.5$ TeV.

$$\Gamma(\mathbb{S} \rightarrow \gamma\gamma) = \frac{\alpha^2 m_S^3}{1024\pi^3} \left| \sum_X n_X^c Q_X^2 \frac{g_X v_S}{M_X^2} A(\tau_S) \right|^2 \quad (10)$$

where the factor $1/2$ in the Eq. (9) comes from $\text{Tr}[\lambda^a \lambda^b]$, with λ^a ($a = 1 \cdots 8$) the generators of $SU(3)_c$; $\tau_X \equiv 4M_X^2/M_S^2$. The loop function can be written as [58]

$$A(x) = x - x^2 f(x) \quad (11)$$

where $f(x) \equiv \arcsin^2(\sqrt{1/x})$ by assuming $2M_X > M_S$. We refer the reader to Ref. [58] for the expression of $f(x)$ when $2M_X < M_S$. There are other decay channels of \mathbb{S} , such as invisible decay, which is relevant to fitting the total width and will be discussed later, and four fermions cascade decays, which are suppressed by the phase space.

Two interesting scenarios will be discussed: scenario (i) \mathbb{S} is a real singlet and there is no extra gauge symmetry; scenario (ii) \mathbb{S} is a complex singlet that triggers the spontaneous breaking of the local $U(1)_{B+L}$ gauge symmetry. We mainly focus on the scenario (i) and will briefly comment on the scenario (ii). We further assume Φ , Ω and Θ have degenerate masses, M_X , and the same couplings, g_X , with the \mathbb{S} just for simplification.

For scenario (i), one has

$$r \equiv \frac{\Gamma(\mathbb{S} \rightarrow gg)}{\Gamma(\mathbb{S} \rightarrow \gamma\gamma)} = \frac{2\alpha_s^2}{\alpha^2} \left(\frac{3}{20} \right)^2 \approx 25.2 \quad (12)$$

by setting $\alpha_s \approx 0.0934$ and $\alpha \approx 1/126.8$. It is the typical character of this scenario. Given this typical input, we plot in the $\Gamma_{\text{tot}}^{\mathbb{S}} - \text{Br}(\mathbb{S} \rightarrow \gamma\gamma)$ plane the region that has $\sigma(gg \rightarrow \mathbb{S} \rightarrow \gamma\gamma) \in (5, 10)$ fb. The vertical dashed line is the best fit width from the ATLAS. For the dot-dashed and dashed horizontal lines, one has $\text{Br}(\mathbb{S} \rightarrow \gamma\gamma) = 7 \times 10^{-4}$ and 1.0×10^{-3} , which separately correspond to $\sigma(gg \rightarrow \gamma\gamma) = 5$ fb and $\sigma(gg \rightarrow \gamma\gamma) = 10$ fb for $\Gamma_{\text{tot}}^{\mathbb{S}} = 45$ GeV. We plot in the left panel of Fig. 3 contours of the $\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$ in the $g_X - \mathbf{v}_{\mathbb{S}}$ plane by assuming $M_X \approx 400$ GeV, where the solid, dotted and dashed lines correspond to $\Gamma(\mathbb{S} \rightarrow \gamma\gamma) = 0.10$ GeV, 0.05 GeV and 0.02 GeV respectively. It is clear that one needs $\mathcal{O}(1)$ quartic coupling g_X and a large VEV $v_{\mathbb{S}}$ to enhance the decay rate. Large quartic couplings is helpful in keeping the vacuum stable up to the Planck scale, but might probably leads to a non-perturbative theory. One might need extra electroweak multiplets to enhance the diphoton rate for the case of small g_X . Apparently a wide width, $\Gamma_{\mathbb{S}}$, can not be explained if there is only $\gamma\gamma$ and gg decay channels, which means there should be other decay channels of \mathbb{S} . Actually, if $2M_X < M_{\mathbb{S}}$, \mathbb{S} might decay into di-scalars, whose decay rate can be written as

$$\Gamma(\mathbb{S} \rightarrow 2X) \approx \frac{g_X^2 \mathbf{v}_{\mathbb{S}}^2}{16\pi M_{\mathbb{S}}^2} \sqrt{M^2 - 4M_X^2}, \quad X = \Theta, \Phi, \Omega \quad (13)$$

This rate can be very large for the light X , and be suppressed when $2M_X \approx M_{\mathbb{S}}$. We show in the right panel of Fig. 3, contours of the decay rate in the $M_X - g_X$ plane by setting $\mathbf{v}_{\mathbb{S}} = 2.5$ TeV. So the wide width of \mathbb{S} can be explained without introducing new ingredients, but this scenario needs to be tuned and is thus less attractive. Alternatively If \mathbb{S} can decay into the hidden valley, a wide $\Gamma_{\mathbb{S}}$ can naturally be explained as was studied in Ref. [14].

Finally we comment on the prediction of the scenario (ii). In this case one needs extra fermions to cancel the global $SU(2)_L$ anomaly [59], axial-vector anomaly [60–62] and the gravitational-gauge anomaly [63–65]. An economic set of new particles are three generations vector-like lepton doublets and singlets: $\psi_{L,R}^1 (1, 2, -1/2, \pm 1)$, $\psi_{L,R}^2 (1, 1, 0, \pm 1)$ and $\psi_{L,R}^3 (1, 1, -1, \pm 1)$. New fermions might get mass through the Yukawa interactions with \mathbb{S} . The lightest neutral component of new fermions can naturally be the dark matter candidate, stabilized by the local $U(1)_{B+L}$ gauge symmetry. As a result, there are extra contributions to the $\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$ from new charged fermions, resulting in enhanced $\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$. Furthermore \mathbb{S} can naturally decay into dark sector in this scenario, which is helpful in deriving the best fit width. For the systematic study of symmetries behind the 750 GeV diphoton resonance,

we refer the reader to Ref. [49] for detail.

IV. CONSTRAINTS AND PREDICTIONS

The run-1 LHC has searched for the pair production of leptoquarks [66], which showed that the first and second generation scalar leptoquarks with the mass less than 1010(850) GeV are excluded for $\text{BR}(X \rightarrow lq) = 1.0(0.5)$. For our case, leptoquarks couple to all three generation fermions, such that branching ratios of leptoquarks decaying into the first and second generation fermions can be suppressed. We show in the right-panel of Fig. 4 the exclusion limit of leptoquark X in the M_X - BR_X plane, given by the CMS [66], where the solid and dashed lines correspond to the exclusion limit of the first and second generation leptoquarks respectively. By assuming the following ratio of Yukawa couplings $\hat{Y}_X^{1\text{gen}} : \hat{Y}_X^{2\text{gen}} : \hat{Y}_X^{3\text{gen}} = 1 : 1.25 : 6$, where $X = \Omega, \Phi$, we show in the right-panel of Fig. 4 the corresponding branching ratios of leptoquarks at $M_X = 400$ GeV. Apparently, they are consistent with the current collider bound of leptoquarks. Alternatively leptoquarks may couple to the hidden valley resulting in suppressed branching ratios of leptoquarks to SM fermions². Embedding leptoquarks into supersymmetry where the mass eigenstate of Bino (\tilde{B}) might be the dark matter candidate, one has the following new interactions: $\mathcal{C}_1 \tilde{B}^T \tilde{\Omega}^c \Omega + \mathcal{C}_2 \tilde{B}^T \tilde{\Phi}^c \Phi + \text{h.c.}$ Then X might decay into \tilde{X} and \tilde{B} . In this way, the current collider constraint will be invalid. A systematic investigation of collider signatures of leptoquarks at the LHC is beyond the reach of this paper and we leave it to a future study.

A second constraint on the model comes from diboson and dijet searches at the run-1 LHC with $\sqrt{s} = 8$ TeV, which have $\sigma \cdot \text{BR}(ZZ) < 12$ fb [67], $\sigma \cdot \text{BR}(WW) < 40$ fb [68], $\sigma \cdot \text{BR}(hh) < 39$ fb [69], $\sigma \cdot \text{BR}(t\bar{t}) < 550$ fb [70]. \mathbb{S} might decay into these final states through its mixing with the SM Higgs. By assuming $\Gamma(\mathbb{S} \rightarrow \gamma\gamma) \approx 0.05$ GeV, one can derive the upper bound on the diboson and dijets decay rates, which on the other hand put upper bounds on the mixing angle θ , describing the mixing between \mathbb{S} and the SM Higgs. We plot in the left panel of Fig. 4 various decay rates as the function of the mixing angle θ , by setting $m_{\mathbb{S}} = 750$ GeV and $v_{\mathbb{S}} = 2.5$ TeV. The solid, dotted, dashed and dot-dashed lines correspond to $\Gamma(\mathbb{S} \rightarrow hh)$, $\Gamma(\mathbb{S} \rightarrow WW)$, $\Gamma(\mathbb{S} \rightarrow ZZ)$ and $\Gamma(\mathbb{S} \rightarrow t\bar{t})$ respectively. Horizontal

² We point out this possibility, but it does not have to be the realistic case.

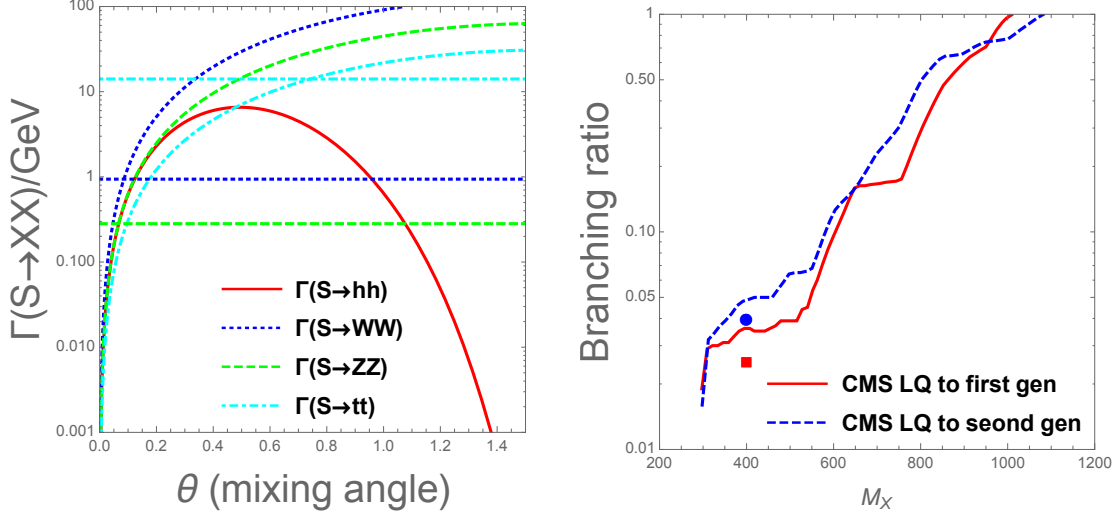


FIG. 4: Left panel: constraint on the mixing angle between the new resonance and the SM Higgs. The solid, dotted, dashed and dot-dashed lines correspond to $\Gamma(S \rightarrow hh)$, $\Gamma(S \rightarrow WW)$, $\Gamma(S \rightarrow ZZ)$ and $\Gamma(S \rightarrow t\bar{t})$ respectively; Right panel: Constraints on the leptoquarks from the CMS collaboration, the red square and the blue circle correspond to the case where $\hat{Y}_X^{1\text{gen}} : \hat{Y}_X^{3\text{gen}} : \hat{Y}_X^{3\text{gen}} = 1 : 1.25 : 6$.

lines are corresponding upper bounds by assuming $\Gamma(S \rightarrow \gamma\gamma) = 0.05$ GeV. Apparently the ZZ channel gives the strongest constraint, which has $\theta < 0.067$. It should be mentioned that this constraint depends on the value of $\Gamma(S \rightarrow \gamma\gamma)_{\text{obs}}$, a large $\Gamma(S \rightarrow \gamma\gamma)_{\text{obs}}$ will loose the constraint.

Finally we check gauge couplings unification in this model, which is an important motivation of extending the SM. β -functions of gauge couplings can be written as

$$\beta_{g_1} = \frac{g_1^3}{16\pi^2} \left(\frac{41}{10} + \frac{4}{3} \right), \quad \beta_{g_2} = -\frac{g_2^3}{16\pi^2} \frac{19}{6}, \quad \beta_{g_3} = -\frac{g_3^3}{16\pi^2} \frac{19}{3} \quad (14)$$

where the SM gauge couplings are normalized based on $SU(5)$ i.e., $g' = \sqrt{3/5}g_1$. Using the couplings, $\alpha_i \equiv g_i^2/4\pi$, given as $(\alpha_1, \alpha_2, \alpha_3) = (0.01681, 0.03354, 0.1176)$ at the Z-pole, one might simulate the running behaviors of gauge couplings, which shows that g_1 crosses with g_2 at $\mu \approx 2.5 \times 10^{11}$ GeV, and crosses with g_3 at $\mu \approx 6.5 \times 10^{13}$ GeV. So there is no gauge couplings unification in this model, but one may approximately get the unification immediately by extending the model with a quadruplet scalar with weak hyper charge 1/2, which might play important rules in generating Majorana neutrino masses via the modified type-III seesaw mechanism [71]. We leave the study of this part to a longer paper.

V. CONCLUSION

A new resonance at invariant mass of 750 GeV was observed by the run-2 LHC in the diphoton channel. If confirmed it will be a manifestation of new physics beyond the SM. In this paper we investigated the possible explanation of this diphoton excess based on a TeV-scale neutrino mass model, that extends the standard model with four scalar singlets, two leptoquarks Ω and Φ , one singly charged scalar Θ and one neutral scalar \mathbb{S} . Majorana neutrino masses are generated at the two-loop level. The diphoton excess is explained as the neutral scalar \mathbb{S} , which is produced at the LHC through the gluon fusion and decays into diphoton at the one-loop level with new charged scalars running in the loop. The value of $\Gamma(\mathbb{S} \rightarrow gg)/\Gamma(\mathbb{S} \rightarrow \gamma\gamma)$ is about $\mathcal{O}(25)$, which is the typical character of this model. It is greatly enhanced comparing with the conventional vector-like quark models. Interestingly the model fits perfectly with a wide width of \mathbb{S} . Constraints on the model was studied, which show a negligible mixing between \mathbb{S} and the SM Higgs. Besides, leptoquarks need to couple with the hidden valley so as to avoid constraints from the LHC run-1. There is no gauge couplings unification (GU) in this model, but GU can be approximately derived by extending the model with a scalar quadruplet. We expect the future high luminosity run-2 LHC could shed light on the resonance in other channels, and show us the gate of new physics.

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